Trans. Am. Fish. Soc., 107(2): 246–254, 1978

Catch Efficiencies of a 6.1-Meter Otter Trawl for Estuarine Fish Populations

MARTIN A. KJELSON[1] AND GEORGE N. JOHNSON

National Marine Fisheries Service, Beaufort Laboratory
Beaufort, North Carolina 28516

ABSTRACT

Gear catch efficiencies, q, are useful in achieving more accurate estimates of fish abundance. Twenty mark-recapture experiments using juveniles (50–80 mm) and yearling (90–140 mm) pinfish, *Lagodon rhomboides*, and spot, *Leiostomus xanthurus*, were conducted in an enclosed 5-hectare North Carolina estuarine embayment to estimate the catch efficiencies for a 6.1-m otter trawl. Catch efficiencies, defined as the percentage of fish in the path of the trawl that are captured, were calculated from the ratio of the average trawl estimate of marked fish density to the known density of marked fish. The trawl was towed at approximately 1.6 knots and sampled a path 5 m wide. Estimated catch efficiencies for the trawl during daylight were: juvenile pinfish 48%; yearling pinfish 49%; juvenile spot 32%; and yearling spot 32%. Precision for the efficiencies was relatively low with the standard error ranging between 9 and 58% of the mean. Catch efficiencies did not differ between day versus night recovery or appear to be related to fish density. Relative catch efficiencies for the 6.1-m trawl were greater than those for a 3.0-m and a 4.6-m otter trawl.

A major requirement for successful solutions to many fishery problems is an accurate estimate of population size. The accuracy of fish abundance estimates for most sampling gears is limited due to insufficient information regarding the catch efficiency of the sampling gear. Given a trawl catch efficiency, defined as the percentage of fish in the path of the trawl that is captured, plus the catch per unit area or volume sampled, raw catch data may be corrected to yield accurate estimates of fish density. Gear catch efficiencies probably vary not only for each species but also for different size classes and for specific environmental conditions (Loesch et al. 1976; Kjelson and Colby 1977). Because of this variability, determination and interpretation of gear efficiencies remain a major and largely unresolved challenge in fishery science (McFadden 1975).

This study was designed to assess the catch efficiency of a 6.1-m otter trawl for two abundant fish populations inhabiting shallow-water estuarine habitat. Small trawls of this general size are commonly used in many estuarine and freshwater areas throughout the world to assess demersal fish, shrimp, and crab populations. Objectives of the study were (1) to determine catch efficiencies of the trawl for two size classes of two estuarine fishes, (2) to assess the variability associated with estimation of these catch efficiencies, (3) to evaluate diurnal differences in catch efficiencies and differences due to varied fish densities, and (4) to compare estimates of relative fish density made by the 6.1-m trawl to those of a 3.0-m and a 4.6-m trawl.

The limited information that is available on trawl efficiencies is based on a variety of techniques from varied aquatic habitats, and information relative to the precision of these efficiency estimates also is scarce. Based upon mark-recapture studies conducted in a Louisiana estuarine embayment, Loesch et al. (1976) estimated the mean efficiency ± one standard error of a 4.9-m otter trawl to be 6 ± 1.3% (N = 3) for spot, *Leiostomus xanthurus*, 25 ± 0% (N = 1) for Atlantic croaker, *Micropogon undulatus*, and 45 ± 3% (N = 5) for brown shrimp, *Penaeus aztecus*. Harden Jones (1974) observed a catch efficiency of 65% for plaice, *Pleuronectes platessa*, using a Granton (otter) trawl in the North Sea. He made use of acoustical transponding tags and a high resolution sector scanning sonar to observe the continual location of individually tagged fish as the trawl was pulled toward them. In a refined study with electric shrimp (otter) trawls in the Gulf of Mexico, Watson (1976) observed catch efficiencies of between 35 and 54% for penaeid shrimp.

[1] Present address: U.S. Fish and Wildlife Service, 4001 N. Wilson Way, Stockton, California 95205.

Kreutzer (1964) noted without documentation that fishery experts estimate that the percentage of fish actually caught by a commercial trawl may vary between 10 and 60%. Edwards (1968), using more qualitative information based upon a combination of general ecological and behavioral evidence and gear observations, estimated catch efficiencies for the "36 Yankee" otter trawl of from 3 to 90% for certain species in the northwest Atlantic area.

The value of catch efficiencies for improving the accuracy of fish abundance estimates has been discussed previously (Beverton and Holt 1957; Grosslein 1971; Macketts 1973), but their use has been greatly restricted. In general, catch efficiencies actually used to improve abundance estimates have been derived theoretically (Alverson and Pereyra 1969; Oviatt and Nixon 1973) or estimated from experimental tests. Edwards and Steele (1968) and Kuipers (1975) used catch efficiencies for the beam trawl in studies of juvenile plaice. Edwards (1973) improved his estimates of tomtate, *Haemulon aurolineatum*, abundance with catch efficiencies for a haul seine. Additional examples of catch efficiencies for other gears and a more general discussion of bias in fish sampling procedures are discussed by Kjelson and Colby (1977).

METHODS

The study site is typical of many shallow marsh embayments that serve as nursery grounds for many estuarine dependent fish and crustaceans in southeastern coastal plain and Gulf coast estuaries. Experiments were conducted in a 400-m by 125-m tidal embayment (Fig. 1) in the Newport River estuary near Beaufort, North Carolina. The bay has an average depth at high tide of 1.3 m (tidal range 0 to 2.5 m) and is surrounded on three sides by smooth cordgrass, *Spartina alterniflora*, marsh with the open end blocked from surface to bottom with a 13-mm bar mesh net. Bottom substrate is a mixture of sand and mud, with a wide shoal running from the southeast to the center of the bay. Secchi readings in the bay ranged from 0.5 to 1.4 m.

The trawl consisted of 19-mm bar mesh wings, a 6-mm mesh tailbag, and a 6.1-m footrope with tickler chain attached. The average width of the trawl during operation was 5 m while the average height was 1 m. Net height was estimated by a diver towed above the net on a separate line attached to the vessel, while width was determined by abruptly stopping the vessel and immediately measuring the distance between wing tips as the net lay on the bottom. Tow speed was approximately 1.6 knots.

Fish used in the study were pinfish, *Lagodon rhomboides*, a sparid, and spot, *Leiostomus xanthurus*, a sciaenid, both very common fishes in southeastern Atlantic and Gulf coasts estuaries. Both juvenile and yearling fish were used with ranges in mean fork length for individual experiments as follows: juvenile spot, 55–85 mm; yearling spot, 102–137 mm; juvenile pinfish 53–79 mm; and yearling pinfish 93–116 mm. Although we used the term yearling, some of these fish may have been older. Studies were conducted during the springs and summers of 1974 through 1976.

Fish were collected by trawl in an adjacent embayment, placed in an oxygenated holding tank, and transported to the study site where they were marked either by fin clipping (1974 and 1975) or by spraying with phosphorescent pigment (1976) (Loesch et al. 1976; Ware 1968) and released throughout the enclosure. The fish lobe that was clipped and the spray colors that were used were changed for each experiment to prevent problems in identification and in calculating density.

The technique used to estimate the trawl's efficiency consisted of releasing marked fish into the enclosed bay, estimating the average density of the marked fish using the trawl and then comparing this estimate to the known density of marked fish in the enclosure. While unmarked populations of pinfish and spot were present in the enclosure during the experiments, these fish were not used in the estimation of catch efficiency since we had only relative estimates of their abundance. Recovery attempts in each experiment consisted of three tows, one tow along the longitudinal axis in each of three zones dividing the bay lengthwise (Fig. 1). The trawl density estimate was obtained by dividing the total

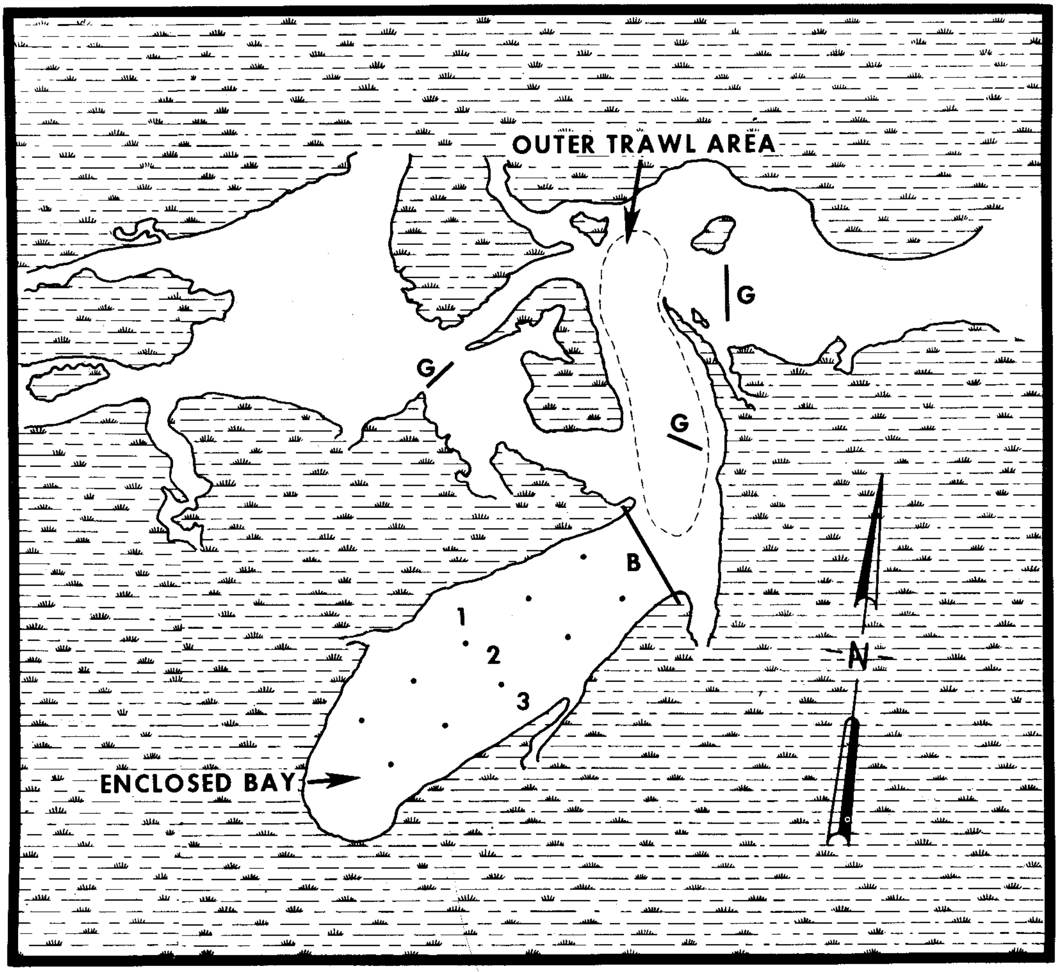

FIGURE 1.—*Enclosed tidal embayment in the Newport River estuary near Beaufort, North Carolina, surrounded by* Spartina alterniflora *marsh. B and G denote locations of blocking net and gill net stations respectively, while numbers 1, 2, and 3 denote location of trawl sampling zones. The enclosed bay is 400 m long.*

catch of marked fish from the three tows by the area sampled in those three tows. The area sampled per tow was determined by multiplying the length of the tow (using the average, 275 m) by the width of the trawl during operation (5 m). With the exception of a few meters of shoreline on the south end of the enclosure, the total bay was trawlable. All recoveries were made at high tide with the majority of studies done during daylight, although some were made during darkness. Usually one size class of each species was released in each experiment. Recoveries were made within 1 h of release (termed immediate) and/or after a delay of from 1 to 3 days (termed delayed). The rationale for making both immediate and delayed recoveries was to observe the effect of recent handling and capture upon the susceptibility of the fish to capture.

The calculation of individual efficiencies based upon the ratio of the trawl estimate of density to the known density, yields values that can theoretically range from zero to greater than 100%. Calculated efficiencies greater than 100%, on occasions when the trawl may encounter a heavy concentration of fish and net avoidance probably still occurs, were set at 100%; such cases are noted in the results.

TABLE 1.—*Results of immediate recovery experiments used to assess the catch efficiency for a 6.1-m otter trawl in a North Carolina estuary.*

Date[a,b]	Age class & species	Mean length mm	Light condition	Number marked & released	Number recovered in 3 tows	% Catch efficiency[c]
4-8-76	Yearling spot	102	Day	595	25	51
4-21-76		109	Day	825	31	46
4-28-76		107	Day	1,405	65	56
5-18-76		112	Day	270	16	72
6-2-76		114	Day	195	5	31
6-24-75	Juvenile spot	79	Day	2,325	84	44
6-25-75		79	Day	1,860	38	25
6-14-76		64	Day	4,975	86	21
6-16-76		69	Day	1,160	13	14
7-14-76		75	Day	680	13	23
7-15-76		75	Day	895	18	24
7-28-76		85	Day	490	8	20
7-28-76		85	Night	673	11	20
4-8-76	Yearling pinfish	94	Day	930	61	79
4-21-76		94	Day	1,425	91	77
4-28-76		93	Day	2,640	255	100 (117)[c]
5-13-76		101	Day	1,295	74	69
5-18-76		99	Day	1,200	113	100 (114)[c]
6-2-76		101	Day	1,475	50	41
6-14-76		98	Day	520	22	51
6-16-76		98	Day	520	36	84
6-26-75	Juvenile pinfish	60	Day	1,585	84	64
6-30-75		65	Day	1,295	79	74
7-14-76		71	Day	535	17	39
7-15-76		71	Day	350	29	100
7-28-76		75	Day	690	28	49
7-28-76		79	Night	437	14	39

[a] Temperature range during study: 16.9 to 27.6 C.
[b] Secchi range during study: 0.5 to 1.4 m.
[c] Value in parenthesis represents calculated catch efficiency that is unrealistic, i.e., greater than 100%. Therefore it was set equal to 100%.

In the delayed recovery experiments, the known density value was corrected for possible loss by mortality and escapement. We assumed that loss due to either escapement or mortality between release and immediate recovery was negligible. Mortality was estimated annually by collecting fish, marking them and holding them for 24 h in a holding cage placed in the estuary. From six to 17 mortality experiments per species were conducted during the study. One series of mortality experiments done in 1975 was used to represent mortality in 1974 and 1975, while two series done in 1976 represent two periods of time in 1976. Estimation of the number of fish escaping from the embayment between release and delayed recovery was made by observing the catches in 6.1-m trawl tows made in the 25,000-m^2 bay immediately adjacent and to the outside of the blocking net, and in gill nets (12-, 19-, and 25-mm bar mesh) set in the channels feeding the enclosed bay (Fig. 1). Two small tidal creeks entering the enclosed bay were also haul-seined (6-mm mesh) immediately following trawl recovery to determine the possible movement of marked fish into this habitat. Two estimates of escapement were made, one based on observations made in 1975 (used for 1974 and 1975) and another made in 1976 (used for 1976).

In an effort to compare the relative efficiencies of the 6.1-m trawl with smaller, 4.6-m and 3.0-m otter trawls, we made two series of 10 paired tows in the embayment, where either of the 4.6- or 3.0-m trawls were towed simultaneously with the 6.1-m trawl using separate vessels. Towing speeds for the two smaller trawls were approximately 1.1 knots, about 0.5 knots slower than the 6.1-m trawl. Mesh size for all three trawls were identical. Analysis was made on the catches of naturally occurring untagged juvenile fishes within the embayment.

TABLE 2.—*Results of delayed recovery experiments used to assess the catch efficiency for a 6.1-m otter trawl in a North Carolina estuary.*

Date[a,b]	Age class and species	Mean length mm	Light condition	Number marked & released	% Loss due mortality & escapement	Estimated number available for recovery	Number recovered in 3 tows	% Catch efficiency[c]
6-28-74	Yearling spot	137	Day	422	42	245	2	10
5-8-75		115	Day	2,603	42	1,509	56	45
5-15-75		119	Day	1,139	42	661	2	4
4-8-76		102	Day	595	82	107	2	23
4-21-76		107	Day	825	72	231	0	0
4-28-76		109	Day	1,405	82	253	3	14
5-18-76		112	Day	270	72	76	0	0
6-3-76		114	Day	195	72	55	0	0
5-8-75		115	Night	2,603	42	1,509	45	36
5-14-75		119	Night	1,139	42	661	6	11
7-22-74	Juvenile spot	82	Day	467	70	140	5	43
5-29-75		66	Day	3,181	70	954	35	44
6-12-75		55	Day	1,678	70	503	9	22
7-18-75		76	Day	1,331	70	399	2	6
6-15-76		64	Day	4,977	96	199	58	100 (353)[c]
6-17-76		65	Day	1,160	96	46	2	53
7-15-76		75	Day	681	96	27	1	45
7-16-76		75	Day	896	96	35	0	0
5-29-75		66	Night	3,181	70	954	24	30
6-11-75		55	Night	1,678	70	503	18	43
7-17-75		76	Night	1,331	70	399	6	18
6-28-74	Yearling pinfish	112	Day	1,522	8	1,400	10	9
7-22-74		116	Day	667	8	614	2	4
5-8-75		113	Day	1,361	8	1,252	51	49
5-15-75		111	Day	1,681	8	1,489	11	9
4-8-76		94	Day	930	8	856	11	16
4-21-76		94	Day	1,425	8	1,311	9	8
4-28-74		93	Day	2,640	8	2,429	114	57
5-13-76		101	Day	1,295	8	1,191	11	11
5-18-76		99	Day	1,200	8	1,104	13	14
6-3-76		101	Day	1,475	7	1,372	1	1
6-15-76		98	Day	520	7	484	9	23
6-17-76		98	Day	523	7	487	28	70
5-8-75		113	Night	1,361	8	1,252	26	25
5-14-75		111	Night	1,681	8	1,489	59	48
7-22-74	Juvenile pinfish	77	Day	555	9	505	42	100
6-12-75		53	Day	1,452	9	1,321	29	27
7-18-75		65	Day	1,514	9	1,378	20	18
7-15-76		71	Day	536	48	277	1	4
7-16-76		71	Day	354	48	184	1	7
6-11-75		53	Night	1,452	9	1,321	13	12
7-17-75		65	Night	1,514	9	1,378	41	36

[a] Temperature range during study: 16.9 to 30.9 C.
[b] Secchi range during study: 0.8 to 1.4 m.
[c] Value in parenthesis represents calculated catch efficiency that is unrealistic, i.e., greater than 100%. Therefore it was set equal to 100%.

RESULTS

The variety of environmental conditions and fish densities under which the efficiencies were measured with the 6.1-m otter trawl are presented in Tables 1 and 2. A summary of daylight experiments (Table 3) indicates differences with species and immediate versus delayed recovery. Daylight catch efficiencies based upon immediate recoveries ranged from 24 to 75% while those based upon delayed recoveries ranged from 12 to 37%. Pinfish were captured more efficiently than spot and immediate recovery efficiencies were larger than those from delayed recovery. The catch efficiencies for both size classes of pinfish were similar, whereas considerable differences, although not consistent, were observed in the efficiencies for juvenile and yearling spot. The ratio of the standard error of the mean to

TABLE 3.—*Average catch efficiencies (±1 SE) of a 6.1-m otter trawl for pinfish and spot obtained during daylight.*

Species and mean size range	Immediate recovery		Delayed recovery[a]	
	N	% Efficiency	N	% Efficiency
Juvenile pinfish (53–79 mm)	5	65 ± 11	5	31 ± 18
Yearling pinfish (93–116 mm)	8	75 ± 7	12	23 ± 7
Juvenile spot (55–85 mm)	7	24 ± 4	8	39 ± 11
Yearling spot (102–137 mm)	5	51 ± 7	8	12 ± 6

[a] Recovery of marked fish delayed 1 to 3 days.

TABLE 4.—*Average day and night catch efficiencies (±1 SE), in percent, of a 6.1-m otter trawl for pinfish and spot.*

Species and age class	Immediate recovery[a]		Delayed recovery[b]			
			Day		Night	
	Day	Night	N	% Efficiency	N	% Efficiency
Juvenile pinfish	49	39	2	22 ± 5	2	24 ± 12
Yearling pinfish			2	29 ± 20	2	36 ± 12
Juvenile spot	20	20	3	24 ± 11	3	30 ± 7
Yearling spot			2	24 ± 21	2	24 ± 13

[a] No replication, all data from 1976.
[b] All data from 1975.

the mean efficiency ranged from 9 to 16% for immediate recovery data and from 29 to 58% for delayed recoveries (Table 3).

No significant differences were observed between the average catch efficiencies obtained from recoveries made during daylight and darkness for either immediate or delayed recoveries (Table 4). The precision characterizing the efficiencies in the day to night comparisons was low due to limited replication of experiments.

No relationship was seen between the efficiency of the trawl and the density of marked fish present in the bay. The numbers of marked fish per experiment released ranged four- to tenfold, dependent on the species and size considered (Tables 1 and 2).

Results of our comparative trawl studies indicated that our 6.1-m trawl provided a larger estimate of fish density by a factor of 1.2 over the 4.6-m trawl and by 7.0 over the 3.0-m trawl (Table 5).

A variety of technique problems may influence the data and its interpretation. The following sections describe some of the problems encountered in a study of fish sampling gear catch efficiencies and our approach and success in solving these problems.

Escapement

Our estimates of escapement from the enclosure between release and delayed recovery was 0 (1976) and 2% (1974–1975) based upon gill net and outer bay trawl catches. Haul-seine catches in the tidal creeks adjacent to the enclosed embayment were either zero or, rarely, a few unmarked fish per haul. Thus we do not consider escapement to be a problem in our study.

Mortalities

Our estimates of handling mortality were highly variable based upon 24-h holding cage experiments following capture and marking. Average mortality estimates in the three study years ranged from 6 to 8% for yearling pinfish, 7 to 48% for juvenile pinfish, 40 to 82% for yearling spot, and 68 to 96% for juvenile spot. Mortality appears to result from collection and overall handling during the marking process since mortalities were similar for both marked and unmarked fish. The average ratio ± one standard deviation of marked to unmarked mortality was 1.19 ± 0.39. Mortalities also were similar for fin clipped fish and for fish marked with sprayed pigment. The average ratio ± one standard deviation of sprayed fish to fin clipped mortality was 1.22 ± 0.44. Long-term holding tank experiments indi-

TABLE 5.—*Average estimates of unmarked, native fish density in numbers per 1,000 m^2 ± 1 SE by the 3.0-, 4.6-, and 6.1-m otter trawls based upon 10 paired tows made in a 50,000-m^2 North Carolina estuarine embayment. Trawl size is length of footrope in meters.*

Species	Comparison 1		Comparison 2	
	6.1-m	4.6-m	6.1-m	3.0-m
Juvenile spot	41 ± 11	34 ± 6	14 ± 2	2 ± 1
Juvenile pinfish	22 ± 4	20 ± 5	32 ± 5	5 ± 1

cated that fin clips were identifiable for at least 3 weeks, while pigment marks lasted a minimum of 2 months. The relationship between tank mortality and field mortality is unknown; however, we feel that the abnormal stress of confinement probably makes tank mortality higher than that experienced by marked fish released in the field.

High estimates of mortality will result in efficiencies that are also too high. This may have caused the relatively high mean delayed recovery efficiency for juvenile spot (37%) (Table 3), which was based upon mortality estimates of from 68 to 96%. The mean yearling spot delayed efficiency was only 12%, yet was based on a relatively high mortality correction of 43 to 72%, indicating that its true efficiency value may be even lower.

Mesh Selection

Due to logistical problems concerning the attainment of sufficient numbers of experimental fish, we were forced, at times, to make use of juvenile spot (those under 70 mm) that had a minimum body dimension that could be pushed through the 19-mm mesh of the trawl wings (Tables 1 and 2). Juvenile pinfish did not appear to be a problem since even a 60-mm individual of that species was held by the mesh of the trawl wing, but some of the variability of resulting efficiencies for juvenile spot may be due not only to active avoidance behavior, but also mesh selection.

Fish Distribution Within Study Site

A basic assumption in our study technique is that the marked fish are accessible to the trawl, both in terms of vertical and horizontal distribution. Pinfish and spot were assumed to be distributed in the lower 1 m of the water column. Comparative daytime trawling experiments, with simultaneous trawling by a 6.2-m surface trawl and a 6.1-m otter trawl, where the two trawls sampled the upper and lower half of the water column, respectively (depth 2 m), resulted in catches of pinfish and spot made only in the otter trawl.

The horizontal distribution of the fish was not felt to influence the efficiencies since the trawl estimate of density was calculated from the catch of all three tows. Although the "known" density estimate was an average value based on a uniform distribution pattern, by spreading the three recovery tows throughout the enclosed bay we felt the effects of a nonuniform fish distribution that may have developed were at least partially overcome. The average coefficients of variation for the catch per tow by species and age classes for the three tows in each experiment ranged from 37 to 63% for immediate recovery experiments and from 37 to 72% for the delayed recoveries.

In an attempt to increase the precision of our trawl estimate of fish density our initial recovery plan was composed of many recovery tows. During 1974, 10 to 20 tows per experiment were made and resulted in marked fish recoveries in the first three to four tows but primarily zero catches thereafter. This indicated that intensive recovery sampling may influence the behavior of the fish to the point where they were less vulnerable to capture. Thus we felt by limiting the number of our recovery tows to three the resulting efficiencies would be more representative of a typical trawl sample.

DISCUSSION

The differences between immediate and the delayed recovery efficiencies make it difficult to be sure as to what values are most appropriate for use in correcting raw catch data. We believe that the greater catch efficiencies for the immediate recovery experiments (Table 3) indicate that the shock of capture and handling make the marked fish more vulnerable to immediate capture and that the effect of these activities decreases through time. It is also possible that the delayed recovery values may be too high for the same reason since we have no information as to the time required to overcome the effect of capture and handling on a fish's vulnerability. As mentioned earlier, the delayed recovery values also may be too high due to the use of abnormally high estimates of mortality.

A reasonable estimate of efficiency would be an average of the results from the respective immediate and delayed recoveries (Table 3) with the catch efficiencies for all species and size classes ranging between approximately 30 and 50% (juvenile pinfish 48%; yearling pinfish 49%; juvenile spot 32%; yearling spot 32%). Corrected estimates of fish density may be achieved by multiplying the reciprocals of these efficiencies by the trawl estimate of fish density based upon raw trawl catches. For example, an accurate estimate of juvenile pinfish density would be achieved by approximately doubling the uncorrected trawl estimate of density. Application of these catch efficiencies for the 6.1-m trawl for the purpose of improving the accuracy of fish density estimates must be restricted to shallow estuarine habitats for the species and size classes studied and the physical and environmental conditions under which the study was conducted.

No differences were observed between the average catch efficiencies obtained from recoveries made in both daylight and darkness (Table 4). The differences in trawl estimates of fish density for native, unmarked fish based on day and night samples taken in the enclosure within 12 h of each other were variable. The average ratio of night to day estimates of density ± one standard deviation ($N = 7$) were 1.95 ± 1.38 for juvenile spot and 1.10 ± 0.85 for juvenile pinfish. Insufficient densities of unmarked adult spot and pinfish were present to allow a similar analysis for this size class to be made. Although the variation surrounding these two ratios was high, the mean ratios indicate that for juvenile spot the night time catch was twice as great as that from daylight tows, while for juvenile pinfish they were similar. Our day-night efficiency values (Table 4), however, indicate that the day-night catches should be similar for all species and size classes, with exception of the conflicting data for juvenile spot. These results suggest that the trawl's catch efficiency does not appear to be influenced by light conditions. It is possible that the high turbidity of the embayment waters, where secchi readings seldom were greater than 1.0 m, limits the ability of fish to utilize visual senses to avoid capture by the trawl.

No relationship between the efficiency of the trawl and the density of marked fish present was apparent although our experimental conditions presented a wide range of abundances for each species and size class (Tables 1 and 2). Densities of unmarked, natural populations within the enclosure also varied considerably throughout the study period. In general, based upon catch data and assuming similar catch efficiencies for natural and marked fishes, marked yearling pinfish and spot densities were similar or greater than those estimated for unmarked populations. Natural juvenile populations, however, appeared either similar or greater than the marked population densities. The effect upon our estimates of catch efficiency due to the additional numbers of unmarked fish within the enclosure is unknown.

Results of our comparative trawl studies suggested that the relative efficiency of the gear increases as the width of the trawl increases. This relation, however, does not appear to be linear since the 4.6-m trawl estimate of density (Table 5) was only slightly smaller than that of the 6.1-m trawl, while the 3.0-m trawl estimate was far less (one-seventh). Although the towing speeds were slower in the smaller trawls (1.1 versus 1.6 knots) all speeds were felt to be near the optimum for the trawl design characteristics to keep the mouth opening at the maximum width and enable the trawl boards to remain on the bottom. Increasing the towing speed will usually lessen the ability of fish to avoid a given trawl; however, tow speed must be chosen in conjunction with the design of the given gear to achieve the optimum performance.

Studies of gear catch efficiency would be improved by collecting fish for marking with a type of gear other than that being tested, or by eliminating the handling, capture, and marking of fish altogether prior to test sampling. This would assure that the behavior of the fish in response to the fishing gear would be typical of that in nature. This approach would require that native fish be restricted to an enclosed body of water for sampling and that the entire sample population be quantified in some way, as sacrificing with poison, draining the sample site (Buck and Thoits 1965), or use of a DeLury regression technique (DeLury 1947; Kjelson and Johnson 1975). An additional improvement would be the use of a larger study site so that sufficient tows could be taken to improve the precision of efficiency estimates without causing behavior changes in the fish that would yield a biased result.

ACKNOWLEDGMENTS

We are very grateful for the help given by many personnel of the Laboratory who assisted with the field work over the study period. Special thanks go to Roland Bell, Ronald Garner, Joseph Johnson, and Robert Terrell who provided extensive assistance in the field sampling and laboratory analysis.

This research was supported through a cooperative agreement between the National Marine Fisheries Service and the Energy Research and Development Administration.

REFERENCES

ALVERSON, D. L., AND W. T. PEREYRA. 1969. Demersal fish explorations in the Northeastern Pacific Ocean—an evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. J. Fish. Res. Board Can. 26(8):1985–2001.

BEVERTON, R. J. H., AND S. J. HOLT. 1957. On the dynamics of exploited fish populations. Fish. Invest. Minist. Agric. Fish. Food (G.B.) Ser. II. Vol. 19. 533 pp.

BUCK, D. H., AND C. F. THOITS, III. 1965. An evaluation of Peterson estimation procedures employing seines in 1-acre ponds. J. Wildl. Manage. 29(3):598–621.

DELURY, D. B. 1947. On the estimation of biological populations. Biometrics 3(4):145–167.

EDWARDS, R., AND J. H. STEELE. 1968. The ecology of O-group plaice and common dabs at Loch Ewe I. Population and food. J. Exp. Mar. Biol. Ecol. 2:215–238.

EDWARDS, R. L. 1968. Fishery resources of the North Atlantic area. Pages 52–60 *in* D. Gilbert, ed. The future of the fishing industry in the U.S. Univ. Wash. Publ. Fish. New Ser.

EDWARDS, R. R. C. 1973. Production ecology of two Caribbean marine ecosystems I. Physical environment and fauna. Estuarine Coastal Mar. Sci. 1:303–318.

GROSSLEIN, M. D. 1971. Some observations on accuracy of abundance indices derived from research vessel surveys. Pages 249–265 *in* Int. Comm. Northwest Atl. Fish. Redbook Part III.

HARDEN JONES, F. R. 1974. Objectives and problems related to research into fish behaviour. Pages 261–275 *in* F. R. Harden Jones, ed. Sea fisheries research. John Wiley Sons, New York.

KJELSON, M. A., AND D. R. COLBY. 1977. The evaluation and use of gear efficiencies in the estimation of estuarine fish abundance. Pages 416–424 *in* M. Wiley, ed. Proc. 3rd Int. Estuarine Res. Conf., Galveston, Tex., Oct. 7–9, 1975. Academic Press, New York.

———, AND G. N. JOHNSON. 1975. Description and evaluation of a portable drop-net for sampling nekton populations. Proc. 27th Annu. Conf. Southeast Assoc. Game Fish Comm. pp. 653–662.

KREUTZER, C. O. 1964. Utilization of fish reaction to electricity in sea fishing. Pages 545–551 *in* Modern fishing gear of the world. Vol. 2. Fishing News Books Ltd., London.

KUIPERS, B. 1975. On the efficiency of a two-meter beam trawl for juvenile plaice (*Pleuronectes platessa*). Neth. J. Sea Res. 9(1):69–85.

LOESCH, H., J. BISHOP, A. CROWE, R. KUCKYR, AND P. WAGNER. 1976. Technique for estimating trawl efficiency in catching brown shrimp (*Penaeus aztecus*), Atlantic croaker (*Micropogon undulatus*) and spot (*Leiostomus xanthurus*). Gulf Res. Rep. 5(2):29–33.

MACKETTS, D. J. 1973. Manual of methods for fisheries resource survey and appraisal. FAO Fish. Tech. Pap. 124. 40 pp.

MCFADDEN, J. T. 1975. Environmental impact assessment for fish populations. Pages 89–137 *in* R. H. Sharm et al., eds. Proc. Conf. on the Biological Significance of Environmental Impacts. U.S. Nucl. Reg. Comm. NR-CONF-002. June 1975, Ann Arbor, Mich.

OVIATT, C. A., AND S. W. NIXON. 1973. The demersal fish of Narragansett Bay: an analysis of community structure, distribution and abundance. Estuarine Coastal Mar. Sci. 1:361–378.

WARE, F. J. 1968. Mass-marking warm water fish by compressed air and fluorescent pigment. Proc. 22nd Annu. Conf. Southeast Assoc. Game Fish Comm. 339–342.

WATSON, J. W., JR. 1976. Electric shrimp trawl catch efficiency for *Penaeus duorarum* and *Penaeus aztecus*. Trans. Am. Fish. Soc. 105(1):135–148.